SURVIVABILITY • SUSTAINABILITY • MOBILITY
SCIENCE AND TECHNOLOGY
SOLDIER SYSTEM INTEGRATION

TECHNICAL REPORT
NATICK/TR-98/002

AD______________

ANALYSIS OF THE EFFECTS OF BODY ARMOR AND LOAD-CARRYING EQUIPMENT ON SOLDIERS' MOVEMENTS

Part I
Technique Comparisons

By
Robert J. Woods
Amy F. Polcyn
Brian E. O'Hearn
Richard A. Rosenstein
Carolyn K. Bensel*

GEO-CENTERS, INC.
Newton Centre, MA 02159

November 1997

FINAL REPORT
February 1996 - December 1996

UNITED STATES ARMY SOLDIER SYSTEMS COMMAND
NATICK RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
NATICK, MASSACHUSETTS 01760-5020
*SCIENCE AND TECHNOLOGY DIRECTORATE

DISCLAIMERS

The findings contained in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

DESTRUCTION NOTICE

For Classified Documents:

Follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For Unclassified/Limited Distribution Documents:

Destroy by any method that prevents disclosure of contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE November 1997	3. REPORT TYPE AND DATES COVERED FINAL Feb 1996 - Dec 1996

4. TITLE AND SUBTITLE
ANALYSIS OF THE EFFECTS OF BODY ARMOR AND LOAD-CARRYING EQUIPMENT ON SOLDIERS' MOVEMENTS
Part I: Technique Comparisons

5. FUNDING NUMBERS
C DAAK60-93-D-0005
AG TB/1368

6. AUTHOR(S)
Robert J. Woods, Amy F. Polcyn, Brian E. O'Hearn,
Richard A. Rosenstein and Carolyn K. Bensel*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
GEO-CENTERS, INC.
Newton Centre, MA 02159

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
*U.S. Army Soldier Systems Command (SSCOM)
Natick Research, Development and Engineering Center
ATTN:SSCNC-YB
Natick, MA 01760-5020

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NATICK/TR-98/002

11. SUPPLEMENTARY NOTES
*Affiliated with Science and Technology Directorate, U.S. Army Soldier Systems Command, Natick Research, Development and Engineering Center

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This is one of three reports of a study on the effects of two types of armor vests and two types of fighting loads on soldiers' movements. Twelve male soldiers performed seven planar movements and a walking task while wearing the vests and fighting loads with either a T-shirt and shorts or the Temperate Battledress Uniform (BDU.) The movements were quantified using two measurement techniques. One was the traditional approach of measuring the extent of movement using a meter stick and a gravity goniometer. The other involved use of video- and computer-based techniques to capture and analyze the movements. This report contains a comparison of the data acquired on the planar movements using the two techniques. It was found that the techniques yielded different values for ranges of motion, with the higher values generally associated with the video-based data. However, the results of the techniques were similar with regard to the relative extent to which the various clothing and equipment configurations tested were found to restrict movements. A second report (NATICK/TR-98/003) contains results of the effects of the vest fighting load designs on movements, and a third report (NATICK/TR-98/004) contains findings from the video-based analysis of gait.

14. SUBJECT TERMS

HUMAN FACTORS ENGINEERING	ARMY PERSONNEL	BODY ARMOR
LOAD CARRYING EQUIPMENT	BODY MOVEMENTS	ARMOR VESTS
FIGHTING LOAD SYSTEM	RANGE OF MOTION	MEASUREMENT

15. NUMBER OF PAGES 40

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

TABLE OF CONTENTS

FIGURES

TABLES

PREFACE

The study reported here was conducted under U.S. Army Soldier Systems Command, Natick Research, Development and Engineering Center contract DAAK60-93-D-0005 with GEO-CENTERS, INC., Newton Centre, MA. The work was performed at the Center for Military Biomechanics Research, Natick Research, Development and Engineering Center. Carolyn K. Bensel of the Center was the project officer for the contract. This project is part of the 6.2 program 1L162723AH98AAKOO (Aggregate Code T/B1368) — Biomechanical Approach to Soldier-CIE Integration, which is being carried out by Dr. Bensel and other members of the Center.

This report is one of a series of three. The references for the other reports are:

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part II: Armor vest and load-carrying equipment assessment* (Tech. Rep. NATICK/TR-98/003). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part III: Gait analysis* (Tech. Rep. NATICK/TR-98/004). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

The authors gratefully acknowledge the technical assistance of Sharon Reinhart and Joelle Stenhouse of the U.S. Army Natick Research, Development and Engineering Center and Bonnie Flynn of GEO-CENTERS, INC.

The citation of trade names in this report does not constitute official endorsement or approval of the use of an item.

ANALYSIS OF THE EFFECTS OF BODY ARMOR AND LOAD-CARRYING EQUIPMENT ON SOLDIERS' MOVEMENTS
Part I: Technique Comparisons

Introduction

A major concern in assessing the acceptability of items of protective clothing and equipment for use by soldiers is the extent to which the items may restrict body movements, thereby impeding mission performance. Research sponsored by this laboratory in the 1950s identified tests of gross motor activities that are sensitive to the effects of different clothing ensembles (Saul and Jaffe, 1955) and established the metrics of the tests (Dusek, 1958b; Dusek and Teichner, 1956). These methods have since been applied by this laboratory in a number of studies of military field clothing (Bensel, Bryan, and Mellian, 1977; Bensel, Teixeira, and Kaplan, 1987; Dusek, 1958a; Lockhart and Bensel, 1977), ballistic protective vests (Bensel, Fink, and Mellian, 1980; Bensel and Lockhart, 1975; McGinnis, 1972), and load-carrying equipment (Bensel et al., 1980; Bensel and Lockhart, 1975). The investigations have generally involved comparisons of standard and developmental items with regard to the relative effects of the items on the body movements of the wearer. The information from the research is used to guide design of military clothing and equipment to ensure that the items are compatible with the mobility requirements of the wearer while also fulfilling their intended functions.

The tests of gross motor performance differ somewhat in how they are carried out, but each yields a quantitative measure of the maximum extent of movement about joints of the body (Saul and Jaffe, 1955). The measurements are made mainly with gravity goniometers. The tests have proven to be reliable, sensitive to clothing and equipment manipulations, and unaffected by practice (Dusek and Teichner, 1956; Saul and Jaffe, 1955). They are also easy to administer and to score.

Although there are positive features associated with these tests of motor performance, the measurement techniques employed do have limitations. For example, the extent of movement about body joints cannot be measured for complex, continuous motions, such as walking and running. Video-based, computer-controlled systems are now available that can be used to analyze videotaped images of continuous movements in a variety of ways. However, the video-based systems, like the traditional techniques, have both positive and negative features.

Consideration of Traditional and Video-Based Measurement Methods

Traditional Methods

Range of motion about body joints is commonly measured with goniometers, simple devices available in several designs (Laubach, 1978) which measure the extent of rotational movement. One design consists of a 180° protractor that is placed over the center of the joint. The protractor has two extended arms; one arm is fixed to 0° and the other is moveable so that it can be aligned with the body part that is being moved. Another design is the gravity goniometer, or flexometer (Glanville and Kreezer, 1937; Leighton, 1942). It is this form of the device that has traditionally been used to measure range of motion as affected by military clothing and equipment (Dusek and Teichner, 1956; Saul and Jaffe, 1955). The gravity goniometer has also been used to assess body movement restrictions associated with wear of fire-fighter turnout gear (Huck, 1988, 1991).

The gravity goniometer consists of a rotatable, weighted pendulum pointer mounted in front of a moveable 360° dial. The pointer and the dial operate independently. When the face of the dial is parallel to a gravity field, the pointer will point directly opposite the direction of the gravity vector (i.e., up). Unlike the protractor design, which must be placed over a joint center, the gravity goniometer is strapped, with hook-and-pile tape, to the body segment that will be in motion. Care must be taken to position the device such that it remains parallel to the field of gravity during the entire movement. With the subject in a predetermined starting position, the goniometer dial is rotated to align the pointer with 0° and the dial is then fixed in this position. The subject performs the movement being tested, and the position of the pointer at the end of the movement is recorded in angular degrees. This measure indicates the number of degrees the body segment was moved in the plane of gravity.

As noted above, gravity goniometers have been used in many studies of clothing and equipment and have proven effective and reliable (Bensel et al., 1977, 1980, 1987; Dusek and Teichner, 1956; Huck, 1988, 1991; Saul and Jaffe, 1955). This method has a number of advantages that make it useful in some situations. The device is lightweight, portable, and does not require power. Thus, it can easily be used outside of the laboratory. The device is also simple to operate and does not need to be calibrated before each testing session. Moreover, the device directly measures angular displacement, the variable usually used in quantifying range of motion. This last fact yields two advantages: (1) The measure can be recorded directly at the time of testing so any obvious errors can be detected immediately and the trial repeated; (2) No potentially time-consuming posttest processing of the data need be performed.

However, gravity goniometers have several limitations. Because the device relies on gravity to move the pendulum, the body movements that can be quantified are limited to those that are made entirely in the plane of gravity, that is the vertical plane. To fully

describe restrictions to normal motion caused by protective clothing or equipment, many body movements outside of the plane of gravity need to be quantified. A related limitation is that, if the subject rotates the body segment during the movement such that the goniometer is even sightly out of the primary plane of movement (i.e., out of the plane of gravity), the angular displacement measured with this device will be inaccurate. In addition, because the device is read only at the beginning and the end of the movement, this method does not provide any information about the path taken during the movement. Moreover, the device can provide a measure of movement about only a single joint; it cannot be used to quantify more complex, multijoint movements, such as those involved in walking. Finally, because the device is somewhat bulky and is strapped directly onto the subject, it can itself cause some movement restrictions not related to the clothing or equipment being evaluated.

In summary, although gravity goniometers are a simple and reliable way of measuring and quantifying several types of human movement, they have a number of limitations related mainly to the limited class of movements they can be used to quantify.

Video-Based Motion Analysis

Video-based methods of motion analysis are growing in popularity and ease of use. Motion analysis systems vary in the types of cameras and other hardware they employ, but they are all based on the same principles. When an object is filmed, it produces a two-dimensional image on the photosensitive surface of the camera. Each point on the object can be considered to be located at specific coordinates in the local/camera coordinate system and at specific coordinates in some global coordinate system. If several points of known relative positions are filmed, a mathematical relationship between the camera coordinates and the global coordinates can be derived. Subsequent movements of unknown magnitude or position can then be filmed, and the mathematical relationship can be used to determine the actual coordinates of the moving body in the videotape. When one camera is used, the global coordinates can be determined in the two-dimensional plane perpendicular to the line of sight of the camera. If more than one camera is used, a relationship between two or more sets of camera coordinates and the actual three-dimensional positions in space of points on a calibration object can be derived, but this is mathematically more complicated than the two-dimensional case.

Operation of video-based motion analysis systems typically entails using one or more video cameras to tape a subject carrying out a movement. Anatomical landmarks and reference points in the taped images are then digitized, a process supported by specialized computer hardware and software. Specialized software is also used to calculate various measures in two or in three dimensions from the digitized data, including linear and angular displacements, velocities, and accelerations of various parts of the subject's body.

Video-based motion analysis has several advantages over the goniometric technique. It can be used to measure planar movements in any plane, not just in the plane of gravity. If more than one camera is used, non-planar movements can be quantified as well. In addition, if a body segment rotates in a secondary plane during the movement, the angular displacement in the primary plane can still be measured accurately. This method also allows for tracking the entire movement if desired, not just the beginning and ending positions. Furthermore, it allows complex, multijoint movements to be quantified. Moreover, because the method does not require that equipment be attached to the subject, the subject's range of motion is not restricted in any way by measuring devices. Finally, the method results in a videotape record of the entire movement so additional analyses can be done at a later date if deemed necessary.

Video-based methods do, however, have some disadvantages. Although it is possible to use the system outside of the lab, this entails moving fragile equipment to the field site, and the conditions for filming are often less than ideal in an uncontrolled environment. In addition, video analysis takes more time (both in terms of calibrating the system and in terms of post-processing of the data) than reading a basic instrument, such as a goniometer. Therefore, when simple movements are to be measured, the time investment may not be cost-effective.

A further consideration when using a video-based motion analysis system is whether to use automatic or manual digitizing options. The automatic option requires that markers that contrast visually with the background (e.g., reflective markers) be placed on the subject's body segments and lamps be used to illuminate the subject. The movement of the markers can then be tracked automatically by the system. This method has the advantage of saving a large amount of time when digitizing longer segments of tape, such as in walking or running trials. In manual digitizing, reflective markers and special lighting are not required; the anatomical landmarks are identified visually on each video frame by the system operator and captured using a mouse. This method has the advantage that a well trained anatomist can track movements accurately even when the subject's body is obscured by equipment or layers of clothing. Layers of clothing may cause extraneous movement of the markers used in the automatic digitizing mode, with the result that the system measures movements that do not accurately reflect the movements of the body segments. Disadvantages of manual digitizing are the time required to process each trial, and the time needed to train personnel to accurately choose the landmarks.

In summary, video-based motion analysis systems are an extremely flexible and fairly simple way to record and quantify human movement under a variety of conditions. They are, however, more complicated and time-consuming than the traditional methods of movement analysis.

Purposes of the Study

The video-based motion analysis systems provide the capability for a more complete, quantitative rendering of a greater variety of human movements than is possible using the traditional measurement techniques. Thus, these systems have the potential for expanding the types of information that can be acquired to guide design of military clothing and equipment. Furthermore, extensive, quantitative descriptions of soldiers' movements under various clothing and equipment conditions are becoming increasingly important as inputs into ever more sophisticated and widely used computer models. The models are employed by military organizations to simulate battlefield maneuvers of individual soldiers and units of soldiers. For these reasons, video-based techniques are now being applied in this laboratory to analyze soldiers' movements as affected by clothing and equipment items. The findings from the first study in which a motion analysis system was used in this laboratory are presented here and in two other reports (Woods, Polcyn, O'Hearn, Rosenstein, and Bensel, 1997a, 1997b).

The first study was designed to address some issues associated with the introduction of the video-based measurement techniques, as well as to investigate the differential effects on soldiers' movements of two designs of armor vest and two designs of load-carrying gear. Seven planar movements were studied using both the traditional and the video-based techniques, and walking gait was analyzed using the video-based techniques. Results of video-based analysis of the effects on planar movements of the armor vests and the load-carrying gear are presented in Woods et al. (1997a). Another report (Woods et al., 1997b) contains findings from the video-based analysis of walking gait as affected by wearing of an armor vest and load-carrying gear.

The purpose of the portion of the study reported here was to evaluate and compare range of motion data acquired using the traditional motion measurement techniques, particularly gravity goniometers, with data acquired using the video-based method. This evaluation was limited to simple, planar movements measured in previous studies using the traditional techniques (Saul and Jaffe, 1955; Bensel et al., 1980). Data were obtained for 18 clothing and equipment configurations. For half of the configurations, the Temperate Battledress Uniform (BDU) coat and trousers were worn as the torso clothing. For the other half, a T-shirt and gym shorts were worn. Thus, data were acquired under conditions in which anatomical landmarks were covered by clothing, as well as under conditions in which landmarks were relatively unobscured. Two successive trials were performed under each of the 18 configurations in order to obtain data on the reliability of the two measurement techniques.

Method

Participants

Participation in this study was limited to individuals who could be accommodated in the sole size in which one of the armor vests was available, a size medium. Twelve male soldiers, who were assigned to the Enlisted Volunteer Platoon at the U.S. Army Soldier Systems Command, Natick, Massachusetts, met this criterion and volunteered to serve in the study. They were fully informed about the purposes and risks of the study and gave their written consent to participate in accordance with Army Regulation 70-25. The participants' demographic information is summarized in Table 1.

Table 1
Participants' Characteristics (N = 12)

Statistic	Stature (cm)	Crotch Ht. (cm)	Chest Circum. (cm)	Waist Circum. (cm)	Age (yrs.)
M	178.12	82.85	100.08	87.48	20.70
SD	6.55	3.17	6.93	7.62	1.54

Clothing and Equipment Conditions

Two types of armor vest were used in the study. One was the Army's standard-issue, fragmentation protective vest that is part of the Personnel Armor System for Ground Troops (PASGT). The other was a prototype vest developed to provide protection against a wider range of ballistic threats than the PASGT vest does. Two types of load-carrying gear were also included in the study. One was the Army's standard-issue fighting load that is part of the All-Purpose Lightweight Individual Carrying Equipment (ALICE) system. The other load-carrying equipment, recently adopted by the Army as a replacement for the ALICE fighting load, was the Tactical Load-Bearing Vest (TLBV). The armor vests and the load-carrying items are described in the appendix.

Participants were tested under 18 combinations of clothing and equipment. In half the conditions, the torso clothing consisted of a T-shirt and gym shorts, and the footwear

was running shoes. In the other half, the coat and trousers of the standard-issue Temperate Battledress Uniform (BDU) were worn along with standard-issue, leather combat boots. Participants were tested wearing these outfits alone and wearing the outfits with the armor vests and the load-carrying gear. The components of each of the 18 clothing and equipment conditions are listed in Table 2.

Apparatus

Traditional Measurement Apparatus

The participants performed seven different movements chosen to demonstrate the range of movement possible about the various joints of the body. On one of the seven movements, a meter stick was used to make a linear measurement. A gravity goniometer was used to measure angular displacement on the remaining movements. The goniometer consisted of a weighted, rotatable pendulum mounted in front of a moveable 360° scale. Both the scale and the pendulum were mounted on a thin block that was attached to a long strap of hook-and-pile tape. The goniometer was strapped to the appropriate part of the body such that it was oriented parallel to the plane of gravity (i.e., in a vertical position). The goniometer was set to zero by turning the moveable scale until the 0° mark coincided with the pendulum. The participant then executed a movement and, when the maximum amplitude of the movement was reached, the degrees of arc through which the body part had passed were read directly by noting the point on the scale with which the pendulum was aligned.

Video Measurement Apparatus

An SVHS shuttered camcorder (Panasonic model AG450), which ran at 60 Hz, was used to videotape the participants as they performed the seven movements. At the beginning of a test session, the camera was checked with a circular bubble level to ensure that it was level in the fore-aft and the lateral directions. A meter stick was also videotaped for use in establishing a scale factor during the tape digitizing process.

After the test sessions, the videotapes were encoded and digitized using specialized computer hardware and software (Peak Performance Technologies, Inc.), a color video monitor (Sony Trinitron model PVM-1341), and an SVHS video cassette recorder (Panasonic model AG7300). The digitizing was done manually by a trained anthropometrist. It consisted of marking previously established anatomical landmarks in the relevant video frames. The landmarks are identified below under the movement descriptions.

For the six movements that involved measurement of angular ranges of motion, two video frames were digitized, one which captured the starting position for the movement and the other which captured the maximum amplitude of the movement. Two

Table 2
Clothing and Equipment Conditions

No.	Components	No.	Components
1.	T-shirt, Shorts, Running Shoes (Shorts)	2.	Temperate Battledress Uniform, Combat Boots (Unif)
3.	T-shirt, Shorts, Running Shoes *plus* PASGT Fragmentation Protective Vest (Shorts + PASGT Vest)	4.	Temperate Battledress Uniform, Combat Boots *plus* PASGT Fragmentation Protective Vest (Unif + PASGT Vest)
5.	T-shirt, Shorts, Running Shoes *plus* Prototype Ballistic Vest (Shorts + Proto Vest)	6.	Temperate Battledress Uniform, Combat Boots *plus* Prototype Ballistic Vest (Unif + Proto Vest)
7.	T-shirt, Shorts, Running Shoes *plus* ALICE Fighting Load (Shorts + ALICE Gear)	8.	Temperate Battledress Uniform, Combat Boots *plus* ALICE Fighting Load (Unif + ALICE Gear)
9.	T-shirt, Shorts, Running Shoes *plus* Tactical Load-Bearing Vest (Shorts + TLBV Gear)	10.	Temperate Battledress Uniform, Combat Boots *plus* Tactical Load-Bearing Vest (Unif + TLBV Gear)
11.	T-shirt, Shorts, Running Shoes *plus* PASGT Fragmentation Protective Vest *plus* ALICE Fighting Load (Shorts + PASGT Vest + ALICE Gear)	12.	Temperate Battledress Uniform, Combat Boots *plus* PASGT Fragmentation Protective Vest *plus* ALICE Fighting Load (Unif + PASGT Vest + ALICE Gear)
13.	T-shirt, Shorts, Running Shoes *plus* PASGT Fragmentation Protective Vest *plus* Tactical Load-Bearing Vest (Shorts + PASGT Vest + TLBV Gear)	14.	Temperate Battledress Uniform, Combat Boots *plus* PASGT Fragmentation Protective Vest *plus* Tactical Load-Bearing Vest (Unif + PASGT Vest + TLBV Gear)
15.	T-shirt, Shorts, Running Shoes *plus* Prototype Ballistic Vest *plus* ALICE Fighting Load (Shorts + Proto Vest + ALICE Gear)	16.	Temperate Battledress Uniform, Combat Boots *plus* Prototype Ballistic Vest *plus* ALICE Fighting Load (Unif + Proto Vest + ALICE Gear)
17.	T-shirt, Shorts, Running Shoes *plus* Prototype Ballistic Vest *plus* Tactical Load-Bearing Vest (Shorts + Proto Vest + TLBV Gear)	18.	Temperate Battledress Uniform, Combat Boots *plus* Prototype Ballistic Vest *plus* Tactical Load-Bearing Vest (Unif + Proto Vest + TLBV Gear)

points, chosen to describe the relevant body segment (e.g., arm, leg), were digitized in each frame. The first point was the approximate center of rotation for the movement, and the second was a more distal point on the segment. Using the specialized computer software, the angles of the segment at the beginning of the movement and at the maximum displacement were calculated with respect to the horizontal. The difference between the initial and final angles was taken as the range of motion on that movement.

Movements

The order in which the movements were performed was not varied throughout the testing. The movements are described here in the order in which they were carried out.

Movement 1: Standing Trunk Flexion

From a standing position on a bench 29 cm high, the participant bent at the waist and, while keeping the knees straight, reached down with both arms toward the floor. This movement was scored manually by measuring with a meter stick the distance between the third fingertip of the right hand and a point marked on the floor. Videotape was recorded from the sagittal view, and the points digitized were the third fingertip and the point marked on the floor. Lower scores on this movement indicate a greater amount of trunk flexion, or less distance between the fingertip and the floor.

Movement 2: Ventral-Dorsal Head Flexion

The participant sat upright in a chair and moved the head forward and down so that the chin was as close to the chest as possible. This was the starting position for the movement. While keeping the shoulders against the back of the chair, the head was then rotated as far back as possible. The goniometer was placed on the right side of the head such that the dial was flush against the side of the head above the ear. Videotape was recorded from the sagittal view. The points digitized were the right acromion (i.e., the outer point at the top of the right shoulder) and the most posterior point on the head. Higher scores on this movement indicate a greater extent of head flexion.

Movement 3: Head Rotation

From a standing position, the participant bent over at the waist until the head and chest were parallel to the floor and grasped the seat of a chair for support. While keeping the rest of the body stationary, the participant rotated the head as far to the left as possible. This was the starting position for the movement. The participant then rotated the head as far to the right as possible. The goniometer was strapped on the top of the head with the dial flush against the top of the head. The participant was positioned such that the top of the head faced the camera. The points digitized were the

approximate axis of rotation of the head and the tip of the nose. Higher scores on this movement indicate a larger angular rotation of the head.

Movement 4: Upper Arm Abduction

The participant stood in the standard anatomical position, with the arms at the sides. This was the starting position for the movement. The right arm was then raised sideward and upward as far as possible while keeping the elbow stiff. The goniometer was strapped on the posterior surface of the right arm just above the elbow such that the dial was approximately parallel to the coronal plane of the body. Videotape was recorded from the coronal view with the participant facing the camera, and the points digitized were the center of the right humeral head and the center of the right elbow joint. Higher scores on this movement indicate a greater range of motion of the arm.

Movement 5: Upper Arm Forward Extension

The participant stood in the standard anatomical position, with the arms at the sides. This was the starting position for the movement. The participant then raised the right arm forward and as far up as possible with the elbow being kept stiff. The goniometer was strapped on the lateral surface of the right arm just above the elbow so that the dial was approximately parallel to the sagittal plane of the body. Videotape was recorded from the sagittal view, and the points digitized were the right acromion and the center of the right elbow joint. Higher scores on this movement indicate a greater range of motion of the arm.

Movement 6: Upper Leg Abduction

The participant stood in the standard anatomical position with feet together and grasped an upright support. This was the starting position for the movement. Maintaining an erect posture, the participant then raised the right leg out to the side as far as possible while holding both knees stiff. The goniometer was strapped on the posterior surface of the right leg above the knee so that the dial was approximately parallel to the coronal plane of the body. Videotape was recorded from the coronal view with the subject facing away from the camera, and the points digitized were the center of the right hip joint and the center of the right knee joint. Higher scores on this movement indicate a greater range of leg motion.

Movement 7: Upper Leg Flexion

The participant stood in the standard anatomical position with feet together and his back against a wall. This was the starting position for the movement. The participant then lifted the right upper leg up as far as possible while letting the lower leg swing freely from the knee. The goniometer was strapped to the lateral surface of the right leg just above the knee so that the dial was approximately parallel to the sagittal plane of the

body. Videotape was recorded from the sagittal view, and the points digitized were the right greater trochanter and the center of the right knee joint. Higher scores on this movement indicate a greater extent of leg flexion.

Procedure

Before testing began, the participants were fitted for the clothing and equipment and familiarized with the movements to be performed. Each man then participated in six experimental sessions, either in the morning or in the afternoon of six days. The sessions for a participant were scheduled for the same time each day. A session lasted approximately 2.25 hr and involved testing three of the 18 clothing and equipment conditions. Each participant was exposed to the clothing and equipment conditions in a different random order. Ambient temperature in the test area was maintained at 19.4 °C.

For each condition, the participant performed two successive trials on all the planar movements and on a walking task while either the traditional or the video-based measurement methods were used. (Findings related to the walking task are presented in Woods et al., 1997b.) Then he repeated this process while the other measurement method was used. The participant spent approximately 5 min completing a questionnaire regarding the extent to which the clothing and equipment being worn hindered his performance. A 10-min rest followed during which any armor or load-carrying gear was removed. Testing resumed with the next condition and continued until three conditions were completed. For half the participants, testing of the conditions was always conducted using the traditional techniques first, followed by the video-based techniques; for the remaining participants, the video-based techniques were used first.

Statistical Analyses

Each of the seven planar movements was analyzed separately. All analyses were carried out on a personal computer using SPSS/PC+, version 3.1. Analyses of variance (ANOVAs) were performed to contrast the traditional and the video-based measurement techniques. The ANOVAs were for repeated measures on four factors. The factors were: Measurement Technique (traditional, video-based), Base Clothing (shorts, uniform), Armor Vest (no armor, PASGT vest, prototype vest), and Load-Carrying Equipment (no gear, ALICE gear, TLBV gear).

The raw data entered into the ANOVAs were the means of a participant's two trials for a clothing and equipment condition using one of the two measurement techniques. The significance level for the analyses was set at $p < .05$. In those instances in which a main effect was found to be significant, Tukey's Honestly Significant Difference (*HSD*) procedure was applied as a post hoc test. The significance level was again set at $p < .05$.

Pearson product moment correlation coefficients (*r*) were also computed on the study data. For each measurement technique, the correlation between two successive trials was calculated for each of the 18 clothing and equipment conditions. For these analyses, the traditional and the video-based data were treated separately, as were each of the seven movements and the 18 clothing and equipment conditions. Thus, *N* equalled 12 in the computation of each correlation.

An *N* of 12 is inadequate to establish the reliability of a test. However, the correlations do provide a gross indication of the reliability of the video-based measurement technique and how the reliability of the technique compares with that of the traditional measurements. In the context of assessing test reliability, the values of correlations are more germane than their significance levels (Anastasi, 1988; Guilford, 1956), but, for completeness, significance levels are indicated in the results of the correlational computations.

Results and Discussion

Of the sources of variance included in the ANOVAs, the ones of interest in this portion of the study are those involving measurement technique. (Findings regarding the effects of the other independent variables on the planar movements are presented in Woods et al., 1997a.) The main effects of measurement technique indicate whether or not scores differed significantly as a function of the measurement method used. The interactions involving measurement technique indicate whether or not the two techniques yielded comparable data with regard to the relative effects on body movements of the base clothing, armor vests, and load-carrying equipment tested.

Differences Between Measurement Techniques

The data acquired using the traditional and the video-based measurement techniques were analyzed to determine whether or not there were differences in the scores obtained using the two techniques. A significant main effect of measurement technique was found in the ANOVAs performed on four of the seven planar movements. These significant main effects are indicated in Table 3, which contains the summarized results of the ANOVAs for all the movements. Table 4 lists the mean scores obtained using each of the two measurement techniques, calculated over the 18 clothing and equipment conditions.

The means in Table 4 reveal that the traditional technique yielded lower scores than the video-based on three of the four movements significantly affected by measurement technique. These movements were Upper Arm Abduction, Upper Arm Forward Extension, and Upper Leg Flexion. On Ventral-Dorsal Head Flexion, the remaining movement significantly affected by measurement technique, the scores obtained with the traditional method exceeded those obtained with the video technique.

Standing Trunk Flexion was the only movement that entailed measurement of linear displacement, and it did not reveal significant differences ($p > .05$) between the traditional and video-based measurement techniques (Table 3). For this movement, the traditional and the video-based methods involved use of the same landmarks, the third fingertip of the right hand and a point marked on the floor. Both methods also involved calculation of the linear distance between the landmarks to obtain the score for the movement. All of the remaining movements entailed measurement of angular displacements. Whether or not the scores obtained for the traditional and the video-based techniques differed significantly on these movements appeared to depend on the body location selected to represent the center of movement rotation and on the form of the movement that the participant was to execute.

Table 3
Summary of ANOVAs for the Planar Movements

		Movement F ratio						
Source of Variance	*df*	1. Trunk Flexion	2. Head Flexion	3. Head Rotation	4. Arm Abduction	5. Arm Extension	6. Leg Abduction	7. Leg Flexion
Subjects (*Ss*)	11	—	—	—	—	—	—	—
Measurement Technique (M)	1	0.56	57.62***	2.94	48.89***	147.41***	0.98	20.65***
Ss x M	11	(2182.52)	(4166.12)	(6866.55)	(1974.04)	(1406.03)	(3213.55)	(2424.13)
Base Clothing (B)	1	23.57***	10.02**	2.30	13.24**	10.51**	22.74***	97.73***
Ss x B	11	(29.82)	(71.82)	(150.25)	(340.31)	(140.45)	(178.73)	(130.98)
M x B	1	0.40	0.26	3.20	1.34	1.93	1.62	0.96
Ss x M x B	11	(21.99)	(117.53)	(110.75)	(359.57)	(283.97)	(166.80)	(63.86)
Armor Vest (A)	2	12.32***	91.92***	36.88***	65.12***	28.23***	4.50*	1.49
Ss x A	22	(26.45)	(128.23)	(181.28)	(119.20)	(110.71)	(53.76)	(80.01)
M x A	2	0.06	2.91	8.89**	2.24	0.82	0.15	0.26
Ss x M x A	22	(16.48)	(104.58)	(103.44)	(115.55)	(123.23)	(76.08)	(90.88)
B x A	2	0.61	0.25	0.12	2.34	1.52	0.33	0.62
Ss x B x A	22	(8.80)	(49.42)	(58.73)	(29.38)	(55.62)	(41.44)	(79.96)
M x B x A	2	0.35	2.14	4.39*	0.15	1.05	0.89	1.98
Ss x M x B x A	22	(9.68)	(39.19)	(94.43)	(65.79)	(80.04)	(52.02)	(53.81)

Table 3 *(Continued)*

		Movement F ratio						
Source of Variance	*df*	1. Trunk Flexion	2. Head Flexion	3. Head Rotation	4. Arm Abduction	5. Arm Extension	6. Leg Abduction	7. Leg Flexion
Load-Carrying Equipment (L)	2	19.53***	20.34***	6.92**	79.22***	15.82***	1.64	12.20***
Ss x L	22	(29.86)	(74.94)	(109.82)	(105.06)	(170.24)	(85.53)	(105.40)
M x L	2	0.31	1.45	0.92	0.24	1.94	0.49	2.23
Ss x M x L	22	(15.37)	(69.02)	(68.27)	(80.67)	(130.29)	(73.64)	(91.85)
B x L	2	0.08	7.82**	1.15	0.09	0.39	0.60	1.23
Ss x B x L	22	(8.93)	(32.83)	(109.78)	(65.51)	(75.22)	(84.11)	(45.11)
A x L	4	0.49	0.91	2.04	4.35**	2.15	1.22	1.07
Ss x A x L	44	(15.46)	(64.69)	(135.16)	(88.88)	(75.13)	(57.12)	(78.46)
M x B x L	2	0.67	1.24	0.19	1.31	0.01	0.53	0.25
Ss x M x B x L	22	(8.70)	(66.30)	(113.05)	(108.10)	(91.15)	(70.58)	(67.80)
M x A x L	4	0.40	0.70	0.36	2.03	1.93	0.15	0.85
Ss x M x A x L	44	(13.64)	(101.76)	(138.29)	(67.44)	(120.29)	(62.72)	(58.91)
B x A x L	4	1.72	2.27	1.54	0.39	1.48	4.14**	2.57
Ss x B x A x L	44	(16.30)	(72.13)	(68.76)	(67.12)	(68.11)	(30.75)	(43.78)
M x B x A x L	4	0.12	0.48	1.76	0.19	0.83	0.87	0.50
Ss x M x B x A x L	44	(11.80)	(67.83)	(44.06)	(59.61)	(70.06)	(33.77)	(67.80)

Note. Values enclosed in parentheses are mean square errors.
$*p < .05$. $**p < .01$. $***p < .001$.

Table 4

Means (and Standard Deviations) of Each Movement Calculated Over All Clothing and Equipment Conditions for Traditional and Video-Based Measurement Techniques and the Differences Between the Technique Means (Traditional Minus Video) ($N = 12$)

Movement	Traditional Method	Video Method	Difference[a]
1. Standing Trunk Flexion (cm)	48.47 (12.95)	45.11 (11.54)	+3.36
2. Ventral-Dorsal Head Flexion (deg)	126.02 (17.25)	78.88 (11.14)	+47.14***
3. Head Rotation (deg)	141.07 (13.74)	127.40 (19.05)	+13.67
4. Upper Arm Abduction (deg)	110.23 (13.12)	140.13 (11.84)	-29.90***
5. Upper Arm Forward Extension (deg)	129.03 (9.86)	172.84 (12.50)	-43.81***
6. Upper Leg Abduction (deg)	57.22 (10.62)	62.63 (13.43)	-5.41
7. Upper Leg Flexion (deg)	78.11 (9.80)	99.64 (10.45)	-21.53***

[a]Asterisks indicate Measurement Technique main effects that were found to be significant in the ANOVAs.
***$p < .001$.

For Head Rotation, one of the two head movements tested, scores did not differ significantly ($p > .05$) with the measurement method used, whereas significant differences between measurement methods were obtained in the analysis of the other head movement, Ventral-Dorsal Head Flexion (Table 3). With regard to Head Rotation, the top of the head was taken as the center of movement rotation in the calculation of the scores for both the traditional and the video-based techniques. For Ventral-Dorsal Head Flexion, on the other hand, slightly different approximations of the center of rotation were used in association with each measurement technique, and the traditional technique yielded scores that were significantly higher than those obtained with the video-based technique.

Head flexion is a complex movement; there is no single center of rotation because the joint at the neck consists of several spinal vertebrae. Thus, over the course of the head movement, from the most ventral to the most dorsal position possible, there is essentially a moving center of rotation in the neck. Measurement of the angle through which the head passes is, therefore, highly dependent on the point that is chosen to approximate the center of rotation.

The gravity goniometer was positioned on the head for the head flexion movement. The goniometer measured the instantaneous angle of the head with respect to a vertical line running through the center of the dial. However, the goniometer itself went through translation, as well as rotation, due to the changing center of rotation at the neck as the head was moved from the ventral to the dorsal position. Unlike the approach taken in acquiring the goniometric data, the video-based data for Ventral-Dorsal Head Flexion were acquired using a fixed center of rotation, the acromion. This point was chosen to estimate the center of rotation because there was no identifiable landmark on the neck that could be digitized consistently. Furthermore, if the position of the acromion is projected onto the plane of rotation for the head flexion movement, the acromion is a good approximation of the center of rotation.

Given the different characteristics of the goniometric and the video-based measurement techniques, the center of rotation used with each method to quantify head flexion seems appropriate. However, it can be maintained that the methods measured different aspects of the movement and, thus, would not be expected to yield comparable scores.

Upper Arm Abduction and Upper Arm Forward Extension, the two arm movements tested, yielded significant differences ($p < .05$) between the measurement techniques (Table 3), and on both movements the goniometric readings were lower than the angles calculated from the video-based data (Table 4). It is unlikely that the differences between the scores for the measurement techniques are attributable to the center of rotation used, because the point on the arm-shoulder girdle that was used as the approximate center of rotation for the video measurement does not move significantly with respect to the instantaneous center of rotation (i.e., the center of rotation for the goniometric measurement) during these movements. The lower scores with the goniometer may be attributable to binding of the arm by the strap used to secure the goniometer. It is also possible that participants did not keep the arm at the maximum angle reached, but rather lowered the arm somewhat during the few seconds required to read the goniometer dial. Lowering of the arm from the maximum point would not affect the video data because the video camera captures the movement continuously from the starting position, through the point of maximum displacement, and back to the starting position. It is also possible that the differences between the scores for the measurement techniques were due to the fact that execution of these arm movements involves some rotation of the head of the humerus in the glenoid fossa as the arm is raised above shoulder level. When this occurs, the goniometer is partially rotated out of the plane of gravity. The result is that the goniometric reading of the angular displacement of the upper arm is lower than the angle through which the arm actually moved. With the video method, on the other hand, the angle is measured accurately as long as the arm as a whole remains in the plane perpendicular to the line of sight of the camera.

Of the two leg movements studied, Upper Leg Abduction and Upper Leg Flexion, scores for the leg flexion movement, but not the leg abduction movement, differed

significantly ($p < .05$) with the measurement technique used (Table 3). On Upper Leg Abduction, therefore, there was no indication that the strap on the goniometer bound the upper leg, limiting the extent of the movement relative to that when the video-based technique was used, or that the time required to read the goniometer resulted in the leg being lowered slightly from its maximum excursion. In addition, the hip was used as the center of rotation in calculating the video measurements, and the actual, instantaneous center of rotation (i.e., the center of rotation for the goniometric measurement) remains effectively coincident with this point throughout the movement. Moreover, during leg abduction, there is little rotation of the head of the femur in the acetabulum. Thus, the goniometer strapped to the upper leg remains parallel to the plane of gravity, and to the plane of movement. The goniometer reading of the angle through which the leg passes would, therefore, be expected to be the same as that calculated from the video data.

On Upper Leg Flexion, the scores obtained using the goniometer were significantly lower ($p < .05$) than those obtained using the video technique in spite of the fact that the same center of rotation, the hip, was used in calculating both the goniometric and the video-based data (Table 4). It is possible that the strap of the goniometer bound the upper leg, limiting the extent of flexion. However, of all the planar movements studied, the leg flexion movement was probably the most difficult for the participants with regard to maintaining the maximum excursion during the few seconds required to take a goniometer reading. It is highly likely, therefore, that participants lowered the leg slightly from the maximum point in order to maintain a stationary standing position while the goniometer was read, a situation obviated with use of the video-based technique.

It appears from the analyses comparing the scores for the two measurement techniques that, regardless of whether or not differences were found, the video-based techniques are an acceptable method for quantifying range of motion. Furthermore, for angular movements in which the goniometer rotates out of the plane of gravity or for which the position at the extreme range of motion is difficult to maintain, the video-based approach may yield a truer value of the extent of the movement.

Interaction of Measurement Technique With Other Independent Variables

Past studies of clothing, armor, and load-carrying equipment in which the traditional techniques were used have typically involved comparing standard and developmental items with respect to their relative effects on the extent of body movements (Bensel et al., 1980; Dusek, 1958a). Thus, a consideration in this study contrasting the traditional and the video-based techniques was whether or not the two measurement techniques yield comparable data in terms of the relative effects on body movements of the items being worn. To investigate this, both measurement techniques were used to acquire data on two types of armor vests and two types of load-carrying gear. Furthermore, half of the clothing and equipment combinations tested included a T-shirt and shorts as the base clothing, a condition in which anatomical landmarks used in

digitizing the video data were relatively unobscured; the other half of the combinations tested included the Temperate BDU, a uniform that covered the body.

The ANOVAs yielded only two instances in there was a significant interaction involving measurement technique (Table 3). Both occurred in the analysis of the Head Rotation data. One was a second-order interaction of measurement technique with the base clothing and the armor variables; the other was a first-order interaction between measurement technique and armor. The second-order interaction is presented graphically in Figure 1.

The data in Figure 1 indicate that, regardless of the base clothing being worn, the lowest scores with both the traditional and the video-based methods were associated with the PASGT vest. For the traditional method, the condition in which armor was not worn

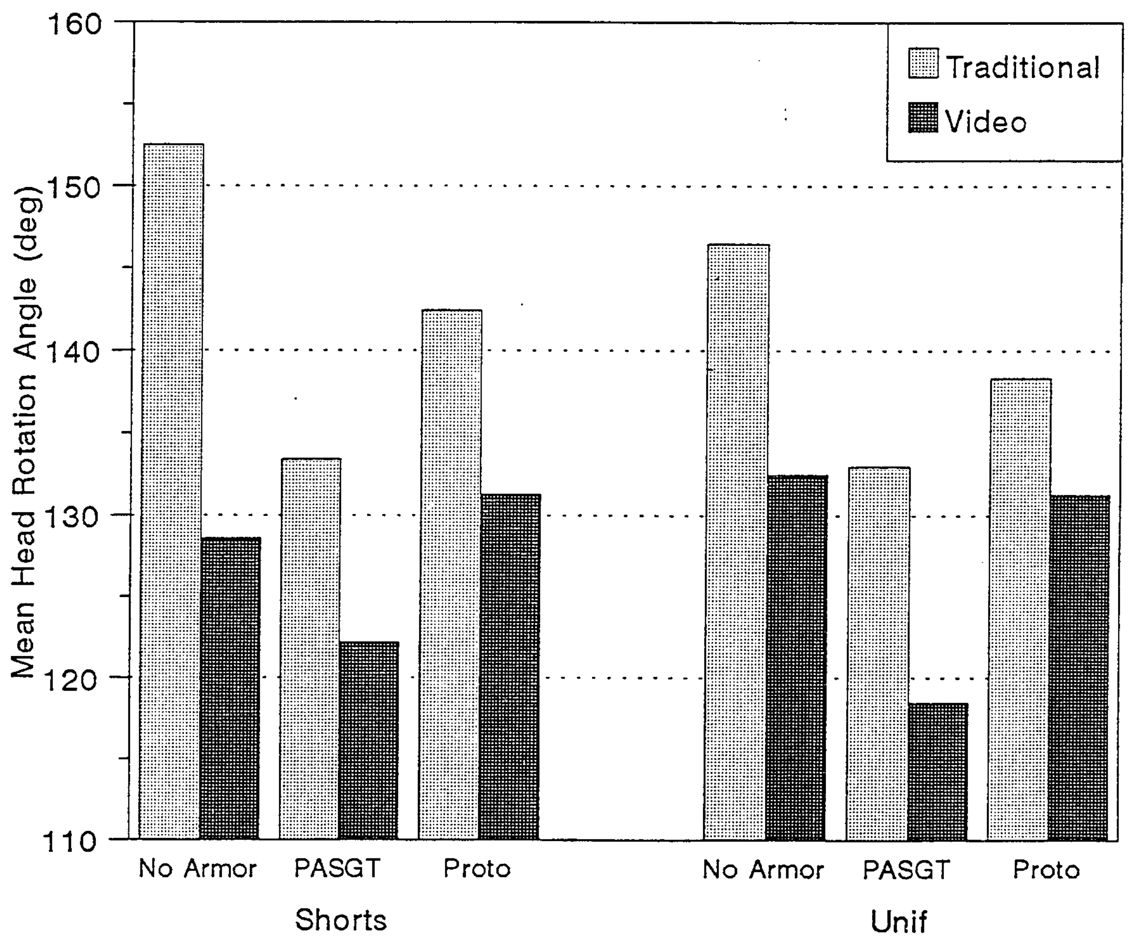

Figure 1. Mean Head Rotation angle for each base clothing and armor condition as measured using traditional and video-based techniques.

resulted in the highest scores under both base clothing conditions. The next highest scores under the two base clothing conditions, those achieved with the prototype vest, were approximately 6% lower than scores for the conditions without armor. The video-based data for Head Rotation differed from the traditional data in that, for the video-based technique, the scores without armor were highest when the uniform served as the base clothing, but the scores for the prototype vest were highest when a T-shirt and shorts served as the base clothing. Furthermore, for the video-based data, the second highest scores under each base clothing condition were only about 2% lower than the highest scores. Thus, regardless of base clothing, the video-based technique did not yield as great a difference between the two highest scores as the traditional data did.

There is no obvious explanation for the significant first- and second-order interactions involving measurement technique that were obtained in the analysis of the Head Rotation movement. The top of the head was taken as the center of rotation in the calculation of both the traditional and the video-based data. The tip of the nose was the second point digitized to obtain the video data for the angular displacement of the head. This point was not obscured by the collar on the uniform or the stand-up collars on the armor vests. Thus, the methods used to make the traditional and the video-based measurements of head rotation do not suggest the reasons that the interactions were significant. The larger issue, however, in the context of the present study is whether or not the two measurement techniques yield similar findings in terms of the relative effects on body movements of clothing, armor vests, and load-carrying gear. Given that only two interactions involving measurement technique were significant, and both were found in the analysis of only one of seven planar movements, it appears that the measurement techniques result in similar findings in terms of relative effects of clothing and equipment on performance.

Intertrial Correlations

The correlations between scores on the two successive trials carried out for a given movement and clothing and equipment condition are presented in Tables 5 and 6. Table 5 contains the correlation coefficients calculated from the traditional measurement data; Table 6 contains the coefficients derived from the video-based data. Regardless of measurement technique, the majority of correlations are above .800. However, the traditional measurement technique yielded higher intertrial correlations overall than did the video-based technique. For the data obtained using the traditional method, eight of the 126 correlations are below .900 and two of these are below .800. For the video-based data, 69 of the correlations are below .900 and 20 of these are below .800.

The trend toward higher *r* values with the traditional technique may be reflective of the fact that, because the measurements are read by the experimenter as a trial is completed, large differences between the scores on two successive trials can be noted immediately and the trial repeated. With the video-based method, on the other hand,

Table 5
Correlation Between Scores for Two Successive Trials Calculated From Data Obtained Using Traditional Measurement Technique

Clothing and Equipment Condition	Movement						
	1. Trk Flex	2. Hd Flex	3. Hd Rotate	4. Arm Abduct	5. Arm Extend	6. Leg Abduct	7. Leg Flex
1. Shorts	.998	.956	.932	.947	.910	.961	.957
2. Unif	.992	.942	.962	.870	.949	.922	.970
3. Shorts + PASGT Vest	.994	.944	.930	.979	.978	.971	.940
4. Unif + PASGT Vest	.987	.975	.963	.957	.981	.982	.941
5. Shorts + Proto Vest	.995	.984	.978	.955	.912	.992	.953
6. Unif + Proto Vest	.980	.974	.898	.967	.890	.966	.949
7. Shorts + ALICE Gear	.990	.961	.971	.955	.946	.938	.995
8. Unif + ALICE Gear	.994	.970	.984	.988	.920	.942	.969
9. Shorts + TLBV Gear	.987	.977	.981	.949	.930	.958	.940
10. Unif + TLBV Gear	.988	.968	.969	.978	.954	.955	.813
11. Shorts + PASGT Vest + ALICE Gear	.994	.951	.921	.957	.867	.982	.959
12. Unif + PASGT Vest + ALICE Gear	.989	.961	.916	.929	<u>.360</u>	.964	.936
13. Shorts + PASGT Vest + TLBV Gear	.997	.991	.955	.987	.978	.978	.956
14. Unif + PASGT Vest + TLBV Gear	.986	.984	.962	.967	.946	.959	.967
15. Shorts + Proto Vest + ALICE Gear	.994	.970	.939	.968	.984	.980	.942
16. Unif + Proto Vest + ALICE Gear	.983	.958	.953	.983	.953	.956	.957
17. Shorts + Proto Vest + TLBV Gear	.994	.987	.982	.988	.959	.987	.959
18. Unif + Proto Vest + TLBV Gear	.982	.957	.987	.918	<u>.757</u>	.904	.888

Note. For $df = 10$, if $.576 \leq r \leq .707$, $p < .05$ and, if $r \geq .708$, $p < .01$. Of 124 r values, 2 (underlined) are less than .800.

Table 6

Correlation Between Scores for Two Successive Trials Calculated From Data Obtained Using Video-Based Measurement Technique

Clothing and Equipment Condition	Movement						
	1. Trk Flex	2. Hd Flex	3. Hd Rotate	4. Arm Abduct	5. Arm Extend	6. Leg Abduct	7. Leg Flex
1. Shorts	.984	.844	.826	.822	.790	.945	.780
2. Unif	.970	.606	.894	.872	.809	.956	.860
3. Shorts + PASGT Vest	.974	.846	.876	.879	.830	.938	.864
4. Unif + PASGT Vest	.987	.822	.849	.938	.902	.828	.494
5. Shorts + Proto Vest	.991	.834	.923	.846	.936	.948	.866
6. Unif + Proto Vest	.985	.773	.892	.961	.809	.923	.795
7. Shorts + ALICE Gear	.927	.876	.882	.927	.969	.939	.899
8. Unif + ALICE Gear	.980	.871	.842	.775	.793	.943	.713
9. Shorts + TLBV Gear	.894	.713	.914	.952	.853	.954	.817
10. Unif + TLBV Gear	.992	.729	.897	.836	.807	.806	.837
11. Shorts + PASGT Vest + ALICE Gear	.987	.888	.895	.886	.917	.926	.960
12. Unif + PASGT Vest + ALICE Gear	.959	.502	.857	.931	.886	.886	.946
13. Shorts + PASGT Vest + TLBV Gear	.988	.768	.959	.796	.937	.873	.860
14. Unif + PASGT Vest + TLBV Gear	.988	.673	.937	.772	.911	.941	.872
15. Shorts + Proto Vest + ALICE Gear	.994	.916	.905	.909	.837	.937	.904
16. Unif + Proto Vest + ALICE Gear	.975	.963	.904	.777	.873	.967	.901
17. Shorts + Proto Vest + TLBV Gear	.971	.788	.972	.846	.932	.989	.875
18. Unif + Proto Vest + TLBV Gear	.866	.575	.891	.929	.741	.960	.822

Note. For $df = 10$, if $.576 \leq r \leq .707$, $p < .05$ and, if $r \geq .708$, $p < .01$. Of 124 r values, 20 (underlined) are less than .800.

posttest processing is required to obtain the score for a trial. The mean absolute differences between trials, calculated over participants for each movement and clothing and equipment condition, provide support for this proposal. Comparisons of the 126 means obtained from the traditional data with those obtained from the video-based data revealed 113 instances in which the mean difference between trials was greater in the video-based data set.

A consideration with the video-based data was whether or not lower *r* values would be associated with the conditions in which the base clothing obscured anatomical landmarks (i.e., conditions using the uniform rather than a T-shirt and shorts). Counts of the number of correlations below .900 and of those below .800 reveal that there are a larger number of these relatively low correlations for the conditions that included the uniform (Table 6). Of the few correlations below .900 obtained in the calculations performed on the traditional data, the conditions with the uniform are also associated with a larger number of the low *r* values than the T-shirt and shorts are (Table 5).

From the perspective of having higher intertrial correlations, the traditional technique is to be preferred to the video-based. However, the higher correlations may not be attributable to the technique per se, but to the fact that the measurement reading is immediately available and, therefore, the trial can be repeated if there are disparate readings. In terms of reliability of video-based data as a function of the clothing worn, the correlation coefficients tended to be lower when body landmarks were covered by the uniform than they were when the T-shirt and shots were worn. However, the same was the case for the traditional data.

Conclusions

Depending on the planar movement performed, the traditional and the video-based techniques yield different values of range of movement. For angular movements, the readings displayed on the goniometer may be lower than the actual extent of the movement because of rotation of the goniometer out of the plane of gravity. With the video-based technique, and using one camera to record the movement, the angle is measured accurately as long as the body part being moved remains in the plane perpendicular to the line of sight of the camera. If more than one camera were used, and a three-dimensional analysis of the captured data were done, non-planar movements could also be quantified. Goniometer readings may also be lower than the maximum extent of the movement because individuals may find it difficult to maintain that body position while a goniometer reading is taken, a problem not encountered with the video-based technique because the camera continuously captures the entire movement. Therefore, compared with the goniometric approach, the video-based method is more robust to movement out of the plane of gravity and provides a truer indication of the range of movement.

A rule of thumb sometimes applied when assessing the reliability of tests is that values of correlation coefficients should equal or exceed .800 (Anastasi, 1988; Guilford, 1956). Based upon the very limited data acquired in this study, the traditional technique is superior to the video-based in this regard. With either method, the vast majority of intertrial correlations exceeded .800. However, the video-based technique was associated with a substantially higher proportion of values below .800 than the traditional technique was. It is likely that this difference is due, at least in part, to the fact that, with the traditional technique, the measurement reading is made immediately by the experimenter and, if the readings on successive trials differ substantially, the trial can be repeated. Although this may result in relatively high intertrial correlations, their values are artificially inflated by the experimenter's intervention. The respective reliabilities of the traditional and the video-based techniques require a better analysis than was done in this study, specifically an analysis in which trials are not repeated and a larger data set is acquired.

Elapsed time between trials was substantially less during the traditional data collection, as the videotaping procedure required a brief amount of pre- and post-trial taping to isolate on the tape the movement to be digitized. This raises the question of whether additional time between trials contributes to variation in an individual's movement pathways. Investigation of the relationship of resting time, "muscle memory," and postural changes with patterns of repeated movements may be revealing.

Studies assessing the effects of protective clothing and equipment on body movements typically involve comparing one item, or a configuration of items, with others to determine which is least restrictive. This is done by examining relative ranges of

motion. The traditional and the video-based methods appear to yield similar findings in terms of the restrictive effects of one item relative to another. Thus, the two measurement techniques could be used interchangeably from study to study, with the procedural constraints of a particular study and other factors dictating the method to use for each study.

Among the factors to be considered in choosing between the methods is the clothing and equipment under study. It may be impossible to position the goniometer properly when some types of clothing or equipment are worn. For example, if the goniometer were strapped to a helmet for the head rotation movement, the quantity measured would be helmet rotation, rather than head rotation. Thus, if there were slippage of the helmet on the head during the movement, the goniometric reading would not accurately indicate the extent of head rotation. In addition, strapping the goniometer over layers of clothing may affect the way the layers move. The clothing and equipment under study can also create problems obtaining accurate data using the video-based technique. When digitizing videotape manually, accurate visual identification of anatomical landmarks is difficult if clothing covers the landmarks. Based upon the results of this study, it appears that the manual digitizing was accomplished very accurately, even when the body was covered by the Temperate BDU. However, this might not have been the case if several layers of clothing were being worn.

Another factor to consider in selecting a measurement technique is the time involved in acquiring and processing data. Goniometric data are immediately available whereas video-based data are acquired through time-consuming posttest processing. The particular movement to be analyzed is also a factor to consider. The traditional methods are severely constraining in this regard, being limited to quantifying simple movements made in the plane of gravity. The video-based methods can capture both the simple, discrete movements included in this study and complex, continuous motions in three dimensions.

Based upon the experience gained using the traditional and the video-based techniques side by side in this study, both seem to have a place in research involving quantification of the effects of protective clothing and equipment on simple, discrete body movements. In a study that investigated only simple planar movements, goniometric techniques would probably be the more efficient approach. On the other hand, in a study dedicated mainly to investigating complex movements, with a few simple planar movements included, it would probably be more efficient to use the video-based technique to collect all the data, rather than use video for some movements and the traditional technique for the others.

References

Anastasi, A. (1988). *Psychological testing* (6th ed.). New York: Macmillan Publishing.

Bensel, C. K., Bryan, L. P., and Mellian, S. A. (1977). *The psychomotor performance of women in cold weather clothing* (Tech. Rep. NATICK/TR-77/031). Natick, MA: U.S. Army Natick Research and Development Command.

Bensel, C. K., Fink, D. S., and Mellian, S. A. (1980). *The psychomotor performance of men and women wearing two types of body armor* (Tech. Rep. NATICK/TR-80/014). Natick, MA: U.S. Army Natick Research and Development Command.

Bensel, C. K., and Lockhart, J. M. (1975). *The effects of body armor and load-carrying equipment on psychomotor performance* (Tech. Rep. 75-92-CEMEL). Natick, MA: U.S. Army Natick Development Center.

Bensel, C. K., Teixeira, R. A., and Kaplan, D. B. (1987). *The effects of U.S. Army chemical protective clothing on speech intelligibility, visual field, body mobility and psychomotor coordination of men* (Tech. Rep. NATICK/TR-87/037). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Dusek, E. R. (1958a). *Encumbrance of arctic clothing* (Tech. Rep. EP-85). Natick, MA: U.S. Army Quartermaster Research and Engineering Center.

Dusek, E. R. (1958b). *Standardization of tests of gross motor performance* (Tech. Rep. EP-81). Natick, MA: U.S. Army Quartermaster Research and Engineering Center.

Dusek, E. R., and Teichner, W. H. (1956). *The reliability and intercorrelations of eight tests of body flexion* (Tech. Rep. EP-31). Natick, MA: U.S. Army Quartermaster Research and Development Center.

Glanville, A. D., and Kreezer, G. (1937). The maximum amplitude and velocity of joint movements in normal male human adults. *Human Biology, 9,* 197-211.

Guilford, J. P. (1956). *Fundamental statistics in psychology and education.* New York: McGraw-Hill.

Huck, J. (1988). Protective clothing systems: a technique for evaluating restriction of wearer mobility. *Applied Ergonomics, 19,* 185-190.

Huck, J. (1991). Restriction of movement in fire-fighter protective clothing: evaluation of alternative sleeves and liners. *Applied Ergonomics, 22,* 91-100.

Laubach, L. (1978). Range of joint motion. In Staff of Anthropology Research Project, Webb Associates (Eds.), *Anthropometric source book. Volume I: Anthropometry for designers* (NASA Reference Publication 1024) (Chapter VI). Houston, TX: National Aeronautics and Space Administration, Lyndon B. Johnson Space Center.

Leighton, T. R. (1942). A simple objective and reliable measure of flexibility. *Research Quarterly, 13,* 205-216.

Lockhart, J. M., and Bensel, C. K. (1977). *The effects of layers of cold weather clothing and type of liner on the psychomotor performance of men* (Tech. Rep. NATICK/TR-77/018). Natick, MA: U.S. Army Natick Research and Development Command.

McGinnis, J. M. (1972). *Some effects of body armor on motor performance* (Tech. Rep. 73-13-PR). Natick, MA: U.S. Army Natick Laboratories.

Saul, E. V., and Jaffe, J. (1955). *The effects of clothing on gross motor performance* (Tech. Rep. EP-12). Natick, MA: U.S. Army Quartermaster Research and Development Center.

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997a). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part II: Armor vest and load-carrying equipment assessment* (Tech. Rep. NATICK/TR-97/003). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997b). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part III: Gait analysis* (Tech. Rep. NATICK/TR-97/004). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

APPENDIX

DESCRIPTIONS OF ARMOR VESTS AND LOAD-CARRYING EQUIPMENT

APPENDIX
DESCRIPTIONS OF ARMOR VESTS AND LOAD-CARRYING EQUIPMENT

Fragmentation Protective Vest, Personnel Armor System for Ground Troops (PASGT Vest)

The standard-issue, PASGT vest is made of 13 plies of ballistic filler. The filler is water-repellent treated Kevlar with a weight of 474.8 g/m^2. The inner and the outer shells are water-repellent treated ballistic nylon with a weight of 271.3 g/m^2. The layer that makes up the inner cover of the vest is olive green. The outer cover is in camouflage colors and design. The ballistic filler in the back of the vest is divided into four sections. The three, upper sections slide over each other and the lower section during body movement. The closure, which runs the length of the front of the vest, is formed with hook and pile fastener tape. The side overlaps are made flexible through the use of sewn-in, elastic webbing that is 3.8 cm wide. The vest also has a fragmentation protective, 3/4 stand-up collar, articulating shoulder pads with elastic webbing and snaps, two front pockets, and rifle butt patches at the shoulders. The ballistic materials in the PASGT vest provide protection from fragmenting munitions. In a size medium, this vest weighs 4.0 kg.

Multiple-Threat Body Armor (Prototype Vest)

This prototype of a multiple-threat vest is identical in design to the PASGT vest. Like the PASGT, it has a 3/4 stand-up collar, a closure that runs the length of the front of the vest, side overlaps, articulating shoulder pads, two front pockets, and rifle butt patches. The inner and the outer shells are made of the same ballistic nylon material, in the same colors, that is used in the PASGT. However, the prototype and the PASGT vests differ in the ballistic filler used. Instead of Kevlar, the ballistic filler in the prototype consists of rigid, metal platelets attached to multiple layers of a fine denier, woven fabric. The woven fabric, which serves as a backing for the platelets, is on the side of the vest closest to the body and the platelets face away from the body. In the PASGT vest, the ballistic filler at the back of the vest is divided into sections. This is done to minimize constraints on the wearer when the torso is flexed. The ballistic filler in the prototype is not divided into sections. To minimize constraints on the wearer, the platelets are laid out such that no platelets overlap. The prototype is available only in a size medium, which is made from the same pattern used for the size medium PASGT vest. The weight of the vest is 3.5 kg.

Fighting Load, All-Purpose Lightweight Individual Carrying Equipment (ALICE Gear)

This standard-issue, load-carrying gear includes an equipment belt that is worn around the waist and suspenders that cross over the shoulders and attach to the front and the back of the belt. Components of the fighting load are attached to the belt. These include two ammunition cases, an entrenching tool with a carrier, and a 1-quart canteen with a cover. Each ammunition case has two external pockets for fragmentation grenades. For this study, the canteen was filled with water and each ammunition case was loaded with weights totalling 1.6 kg to simulate the weight and the bulk of three, 30-round magazines of M16 ammunition. One of the two grenade pockets on each ammunition case was filled with weights totalling 0.5 kg, the weight of a fragmentation grenade. The total weight of the ALICE fighting load was 7.8 kg.

Tactical Load-Bearing Vest (TLBV Gear)

· The basic components of this load-carrying gear are a vest and a waist belt. The belt is the same one that is part of the ALICE fighting load. The vest, which is made of nylon, has a front opening that is secured by two, horizontal straps with plastic buckles. One strap is slightly above the level of the sternum and the other is slightly above the level of the waist. There are two parts to the vest: shoulder straps and a torso portion. The parts of the vest that pass over the shoulders are padded and have strips of webbing that are connected in the back and in the front by buckles to the torso portion of the vest. By use of the buckles and webbing, the vest can be raised and lowered on the torso. On the upper back of the vest, there is also a wide band of webbing, positioned horizontally, that is sewn to both shoulder straps and serves to keep the straps from slipping off the wearer's shoulders. Below the webbing is a panel of material that is secured to the front part of the vest by lacing. The purpose of this feature is to allow the wearer to adjust the circumference of the vest to conform to the circumference of the torso by using the lacing. Placed around the bottom edge of the vest are 10 loops. The waist belt is passed through the loops and thereby secured to the vest. Four ammunition pockets are sewn in a row on the front of the vest, at about the level of the chest. Two pockets are large enough to hold two, 30-round magazines each. Each of the other two pockets holds one, 30-round magazine. Two, smaller pockets are sewn below the ammunition pockets. Each of the smaller pockets accommodates one fragmentation grenade. Additional components of this load-bearing gear are an entrenching tool with a carrier and a 1-quart canteen with a cover. These are the same items that form part of the ALICE fighting load. As in the case of the ALICE, the entrenching tool and the canteen are attached to the waist belt. For this study, the canteen was filled with water. The larger ammunition pockets were each loaded with weights totalling 1.1 kg, the weight of two, 30-round magazines. Each of the smaller ammunition pockets was loaded with weights of 0.5 kg, the weight of one, 30-round magazine. Weights of 0.5 kg were placed in each grenade pocket. The total weight of this load-bearing gear was 9.1 kg.